Space Environment
TOPICS

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SE-16

Satellite Anomalies

At the end of the 20th century we are seeing a rise in the use of satellites by the average American as they use cellular phones, television, and position-finding systems. About 700 new satellites (valued at $30 billion) will be launched between 1998 and 2003.

Space weather will exert effects on spacecraft that vary according to the orbit and the position of the satellite and are caused by the changing nature of the Sun (figs. 1 and 2). While satellites can be designed to avoid the many problems in the space environment, most of the new satellites have been designed to meet other criteria: principally small and light, therefor easier and cheaper to launch. As part of the new design, they have less shielding, less redundancy, higher density of parts, and higher signal output. They are flown closer together, thus will experi-

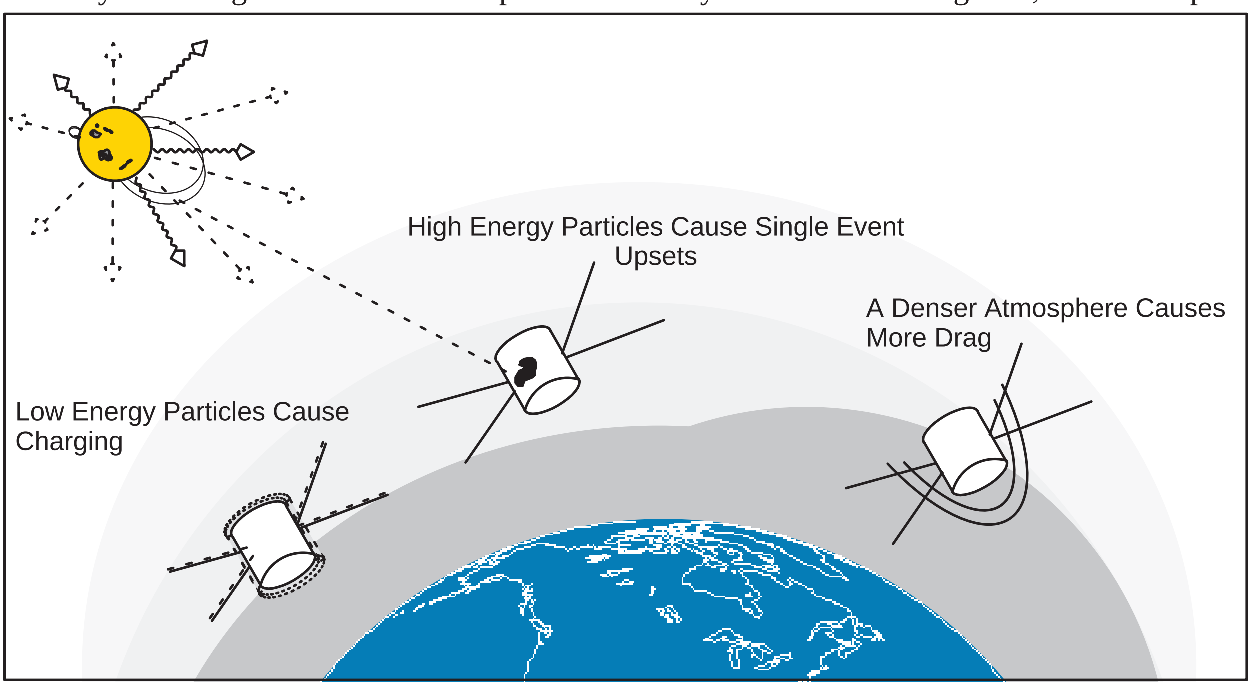

Fig. 1—Effects on Satellites: Outages and Orbital Decay

ence environment problems in clusers. In short, they are more vulnerable than older satellites.

A satellite is susceptible to many ills from many sources. While only some of them are caused by space weather, many types of spacecraft anomalies can be caused by various aspects of space environment.

Electrical Charging

One of the most common anomalies caused by radiation hazards is spacecraft or satellite electrical charging. Charging can be produced three ways.

- by an object's motion through a medium containing charged particles (called "wake charging"), which is a significant problem for large objects like the Space Shuttle or a space station.
- directed particle bombardment, as occurs during geomagnetic storms and proton events.
- solar illumination, which causes electrons to escape from an object's surface (called the "photoelectric effect").

The impact of each phenomena is strongly influenced by variations in an object's shape and the materials used in its construction. An electrostatic discharge can produce spurious circuit switching; degradation or failure of electronic components, thermal coatings, and solar cells; or false sensor readings. In extreme cases, a satellite's life span can be significantly reduced, necessitating an unplanned launch of a replacement satellite. An electrical charge can be deposited either on the surface or deep within an object, resulting in two types of charging:

- *Surface charging*—low energy electrons attach to the spacecraft causing different charges on parts of the spacecraft leading to an electrical arc discharge on the surface. Solar illumination and wake charging are surface charging phenomena.
- *Deep dielectric charging*—high energy electrons penetrate through the shielding of the spacecraft and build up in dielectric insulators and conductors such as coax cable. A charge can build up until it reaches a breakdown point of that particular dielectric and an electrical discharge occurs. The higher the energy of the bombarding

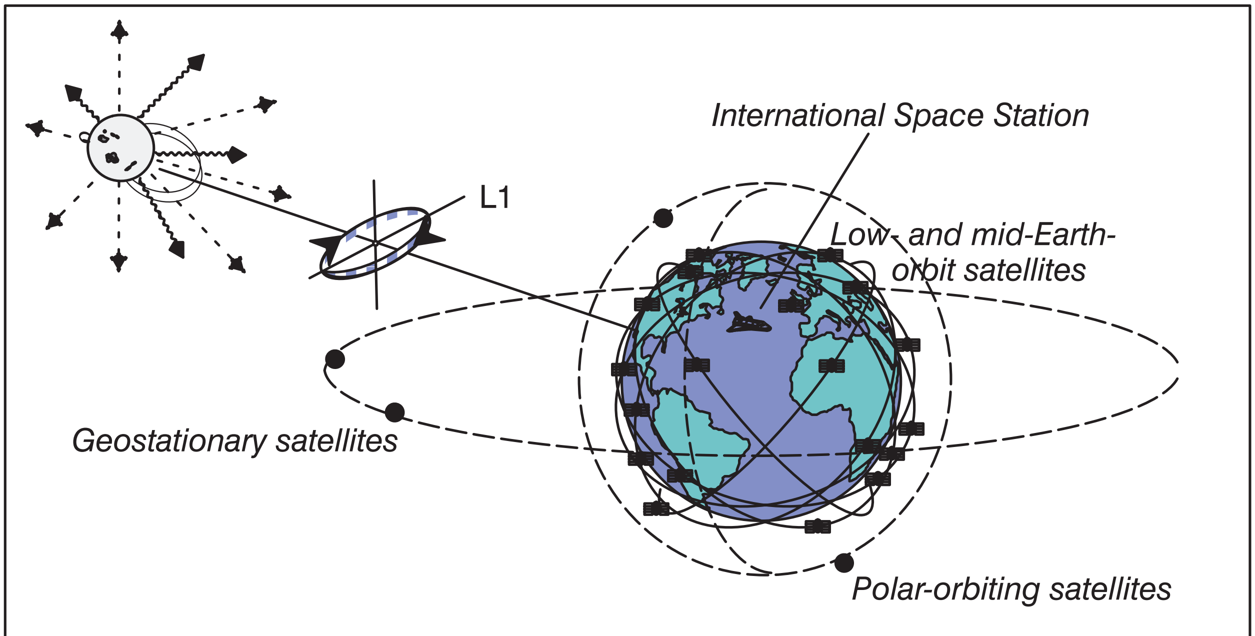

Fig. 2—Space Environment Impacts Near-Earth Space. Examples of air and spacecraft that are affected are GOES weather satellites, communications satellites, GPS, the International Space Station, and the Concorde.

particles, the deeper the charge can be placed.

Normally electrical charging will not (in itself) cause an electrical upset or damage. It will deposit an electrostatic charge which will stay on the vehicle (for perhaps many hours) until some triggering mechanism causes a discharge or arcing. Such mechanisms include a change in particle environment, a change in solar illumination (like moving from eclipse to sunlit), or on-board vehicle activity.

Single Event Upsets

Single Event Upsets, or SEUs, are caused by very high energy particles which penetrate the shielding and hit memory devices, causing memory changes and physical damage. The high energy particles have two sources: cosmic rays, which are a slow steady flux of high energy, sometimes of heavy particles and (2) solar proton emissions of very large fluxes from solar flares.

In fact, a single proton or cosmic ray can (by itself) deposit enough charge to cause an electrical upset (circuit switch, spurious command, or memory change or loss) or serious physical damage to on-board computers or other components. Hence these occurrences are called "single event upsets." SEUs are very random, almost unpredictable events. They can occur at any time during the 11-year Solar Cycle (fig. 3). In fact, SEUs are actually most common near Solar Minimum, when the Interplanetary Magnetic Field emanating from the sun is weak and unable to provide the Earth much shielding from cosmic rays originating outside the Solar System.

Radiation Hazards

Total dose effects—radiation from galactic cosmic rays and solar proton events can cause cumulative radiation damage, such as results when

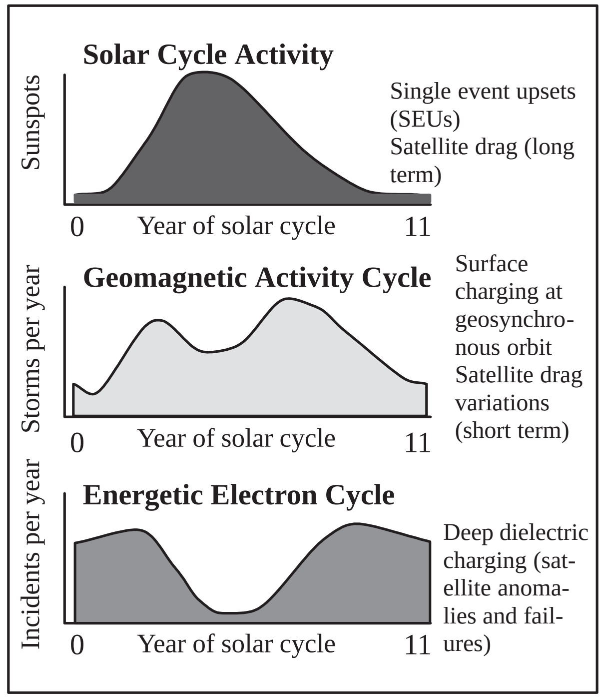

Fig. 3—Satellite are at risk all during the Solar Cycle.

solar panels decrease the voltage they can generate as the damage accumulates.

Despite all engineering efforts, satellites are still quite susceptible to the charged particle environment; in fact, with the newer microelectronics and lower voltages, it will actually be easier to cause electrical upsets than on the older, simpler vehicles. While the components are built to withstand the harsh environment, they can fail after repeated exposure to large storms. Both low and high earth-orbiting spacecraft and satellites are subject radiation hazards.

Spacecraft drag and Orbital Tracking

Ultraviolet flux from the Sun and disturbances in the Earth's magnetic field combine to heat the upper atmosphere and slow the lower Earth orbiting satellites, causing earlier fall to Earth. Satellites affected by atmospheric drag may require costly orbit maintenance maneuvers. However, predictions of when a satellite will tumble out of orbit become unreliable. A classic case of the later was the premature loss of Sky Lab. Geomagnetic activity was so severe, for such an extended period, that Sky Lab de-orbited and burned-in before a planned Space Shuttle rescue mission was ready to launch.

In addition to causing satellites to change orbits, the many bits of space debris also are affected by drag, and the careful tracking of this "junk" must be adjusted for that. The space shuttle and space station are particularly concerned with accurate tracking.

Disorienting magnetic fluctuations and discharges

Some spacecraft that use the Earth's magnetic field to help orient themselves can lose orientation during a geomagnetic storm. Many satellites rely on electro-optical sensors to maintain their orientation in space. These sensors lock onto certain patterns in the background stars and use them to achieve precise pointing accuracy. High energy particles can actually release flashes of light in such devices as star trackers, charge couple devices (CCDs), and optical devices. They can cause misorientation in the star tracking devices or misreadings in sensors, causing the satellite to lose attitude lock with respect to the Earth. Directional communications antenna, sensors, and solar cell panels would then fail to see their intended targets. The result may be loss of communications with the satellite; loss of satellite power; and, in extreme cases, loss of the satellite due to drained batteries. (Gradual star sensor degradation can also occur under constant radiation exposure.) Disorientation occurs primarily on geosynchronous or polar-orbiting satellites when solar activity is high.

Radio interference

A satellite's telemetry may be masked by a solar radio frequency burst when the Sun is aligned with the satellite and the ground antenna. The problem lasts only for the duration of the alignment.

Radio propagation problems through and within the Ionosphere are caused by space weather, and affect nearly all satellites to a greater or lesser extent. However, we will not cover that subject in this paper. (Refer to *Space Environment Topics SE-10*, "Radio Propagation," 1994)

Analysis of Failure

Often times, analysis of a satellite failure or anomaly is done to determine its cause. The type of failure, which is not always known, and the conditions of the environment may provide enough clues to determine the cause. Certain conditions are well known for causing specific problems. Energetic proton events can cause increased noise in photonics, single event upsets, total dose problems or power panel damage. A heightened electron flux (10^3) in the greater-than-2-Mev range usually correlates with deep dielectric charging at geosynchronous orbit.

The natural trade-off between needing to build a robust, space-weather-hardened satellite and the need to keep down the cost and weight of the satellite makes space weather a factor in the satellite business. In design of the satellite and in its operations, space weather plays a role in the nation's economy, and affects the ever-increasing technology that depends on satellites.

Additional Information

More detailed information concerning satellite anomalies is in the SEC paper "Satellites and Space Weather" on the SEC Web site *http://sec.noaa.gov/SatOps/*

Other Web Site References

The Aerospace Corporation, Research and Technology Solutions (http://www.aero.org/research/)

Space Science Institute, Space Weather Center (http://www.spacescience.org/WOP/NSWP/)

Space Weather: A Research Perspective (http://www.nas.edu/ssb/swconsequences.html/)

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